US009187009B2

(12) **United States Patent**
Jeon et al.

(10) **Patent No.: US 9,187,009 B2**
(45) **Date of Patent: Nov. 17, 2015**

(54) **APPARATUS AND METHOD FOR CONTROLLING COOLING OF ELECTRONIC COMPONENTS OF FUEL CELL VEHICLE**

(71) Applicant: **Hyundai Motor Company**, Seoul (KR)

(72) Inventors: **Soonil Jeon**, Yongin-Si (KR); **Kyuil Lee**, Yongin-si (KR); **Dae Jong Kim**, Yongin-si (KR)

(73) Assignees: **HYUNDAI MOTOR COMPANY**, Seoul (KR); **KIA MOTORS CORPORATION**, Seoul (KR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/103,511**

(22) Filed: **Dec. 11, 2013**

(65) **Prior Publication Data**

US 2014/0358341 A1 Dec. 4, 2014

(30) **Foreign Application Priority Data**

Jun. 3, 2013 (KR) 10-2013-0063706

(51) **Int. Cl.**
B60L 11/00 (2006.01)
B60L 11/18 (2006.01)

(52) **U.S. Cl.**
CPC ***B60L 11/1892*** (2013.01); *Y02E 60/50* (2013.01); *Y02T 10/7005* (2013.01)

(58) **Field of Classification Search**
USPC 701/22; 180/65.1, 65.21, 65.225
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,006,425	A *	4/1991	Takabayashi	429/423
7,311,984	B2 *	12/2007	Ueda et al.	429/438
7,395,787	B1 *	7/2008	Claypole et al.	123/41.01
7,682,717	B2	3/2010	Ueda et al.	
8,241,805	B2 *	8/2012	Ueda et al.	429/434
8,613,334	B2 *	12/2013	Masaki	180/65.31
8,783,396	B2 *	7/2014	Bowman	180/65.285
2011/0060470	A1 *	3/2011	Campbell et al.	700/282
2013/0128918	A1 *	5/2013	Campbell et al.	374/57
2013/0333865	A1 *	12/2013	Goth et al.	165/104.31

FOREIGN PATENT DOCUMENTS

JP	2004328914	A	11/2004
JP	4686290	B2	5/2011

* cited by examiner

Primary Examiner — Yonel Beaulieu
(74) *Attorney, Agent, or Firm* — McDermott Will & Emery LLP

(57) **ABSTRACT**

An apparatus and method for controlling cooling of electronic components of a fuel cell vehicle are provided. The apparatus for controlling cooling of electronic components connected in series and parallel with a coolant loop in a fuel cell vehicle using a pump includes a monitor configured to collect measured temperature of the electronic components and a measured temperature of a coolant through a plurality of temperature sensors, and a controller configured to control the RPM of the pump based on the measured temperatures and at least one of electronic component temperature maps, a coolant temperature map and a temperature difference map representing temperature differences between the electronic components and coolant, the controller controlling the RPM of the pump using over-temperature set information and over-temperature reset information of each temperature map.

16 Claims, 5 Drawing Sheets

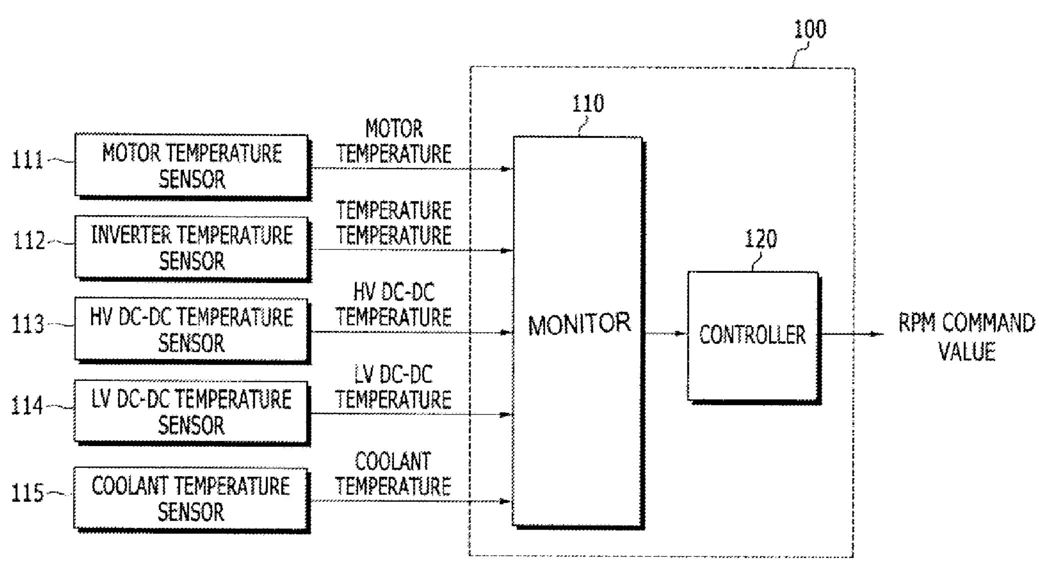


FIG. 1
(Prior Art)

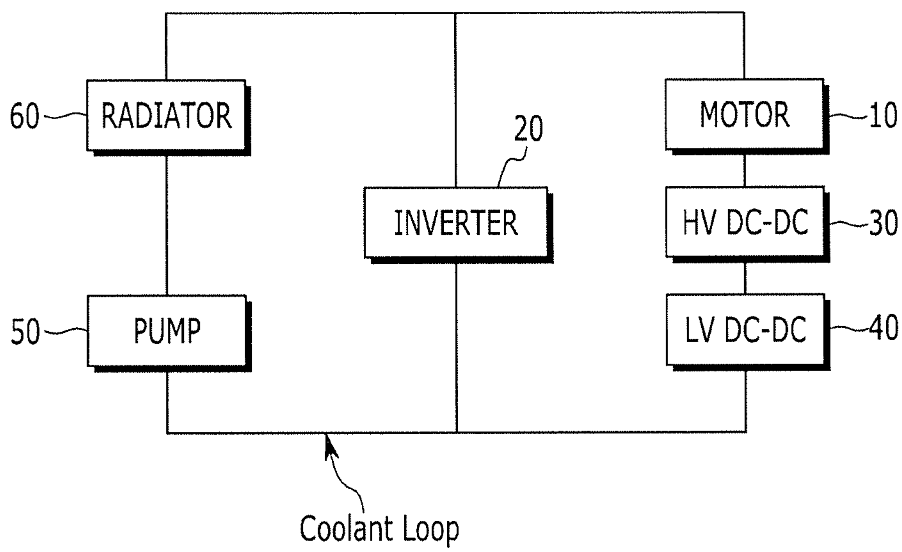


FIG. 2

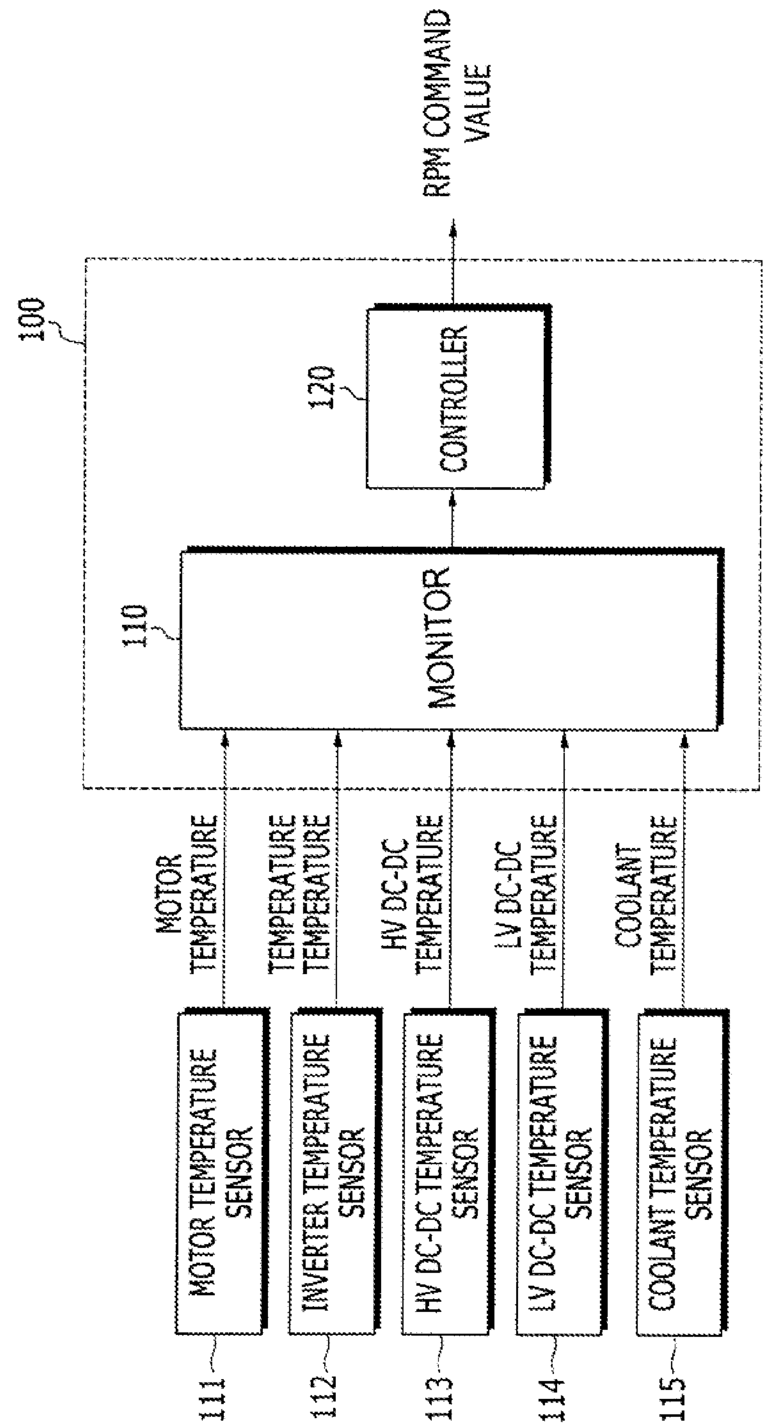

RPM COMMAND VALUE
100
120
CONTROLLER
110
MONITOR
MOTOR TEMPERATURE
TEMPERATURE TEMPERATURE
HV DC-DC TEMPERATURE
LV DC-DC TEMPERATURE
COOLANT TEMPERATURE
MOTOR TEMPERATURE SENSOR
INVERTER TEMPERATURE SENSOR
HV DC-DC TEMPERATURE SENSOR
LV DC-DC TEMPERATURE SENSOR
COOLANT TEMPERATURE SENSOR
111
112
113
114
115

FIG. 3

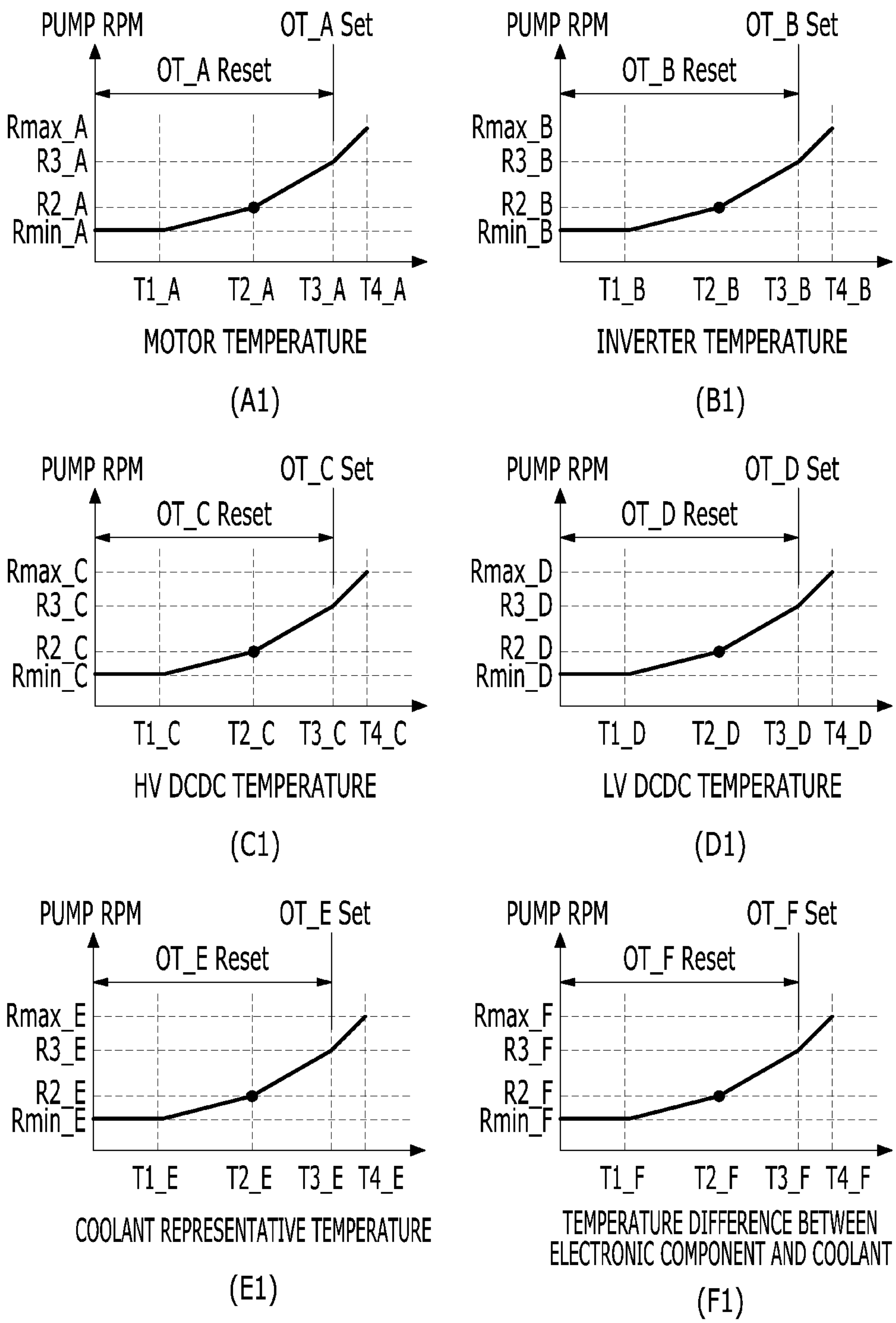

PUMP RPM
OT_A Set
OT_A Reset
Rmax_A
R3_A
R2_A
Rmin_A
T1_A T2_A T3_A T4_A
MOTOR TEMPERATURE
(A1)
PUMP RPM
OT_B Set
OT_B Reset
Rmax_B
R3_B
R2_B
Rmin_B
T1_B T2_B T3_B T4_B
INVERTER TEMPERATURE
(B1)
PUMP RPM
OT_C Set
OT_C Reset
Rmax_C
R3_C
R2_C
Rmin_C
T1_C T2_C T3_C T4_C
HV DCDC TEMPERATURE
(C1)
PUMP RPM
OT_D Set
OT_D Reset
Rmax_D
R3_D
R2_D
Rmin_D
T1_D T2_D T3_D T4_D
LV DCDC TEMPERATURE
(D1)
PUMP RPM
OT_E Set
OT_E Reset
Rmax_E
R3_E
R2_E
Rmin_E
T1_E T2_E T3_E T4_E
COOLANT REPRESENTATIVE TEMPERATURE
(E1)
PUMP RPM
OT_F Set
OT_F Reset
Rmax_F
R3_F
R2_F
Rmin_F
T1_F T2_F T3_F T4_F
TEMPERATURE DIFFERENCE BETWEEN
ELECTRONIC COMPONENT AND COOLANT
(F1)

FIG. 4

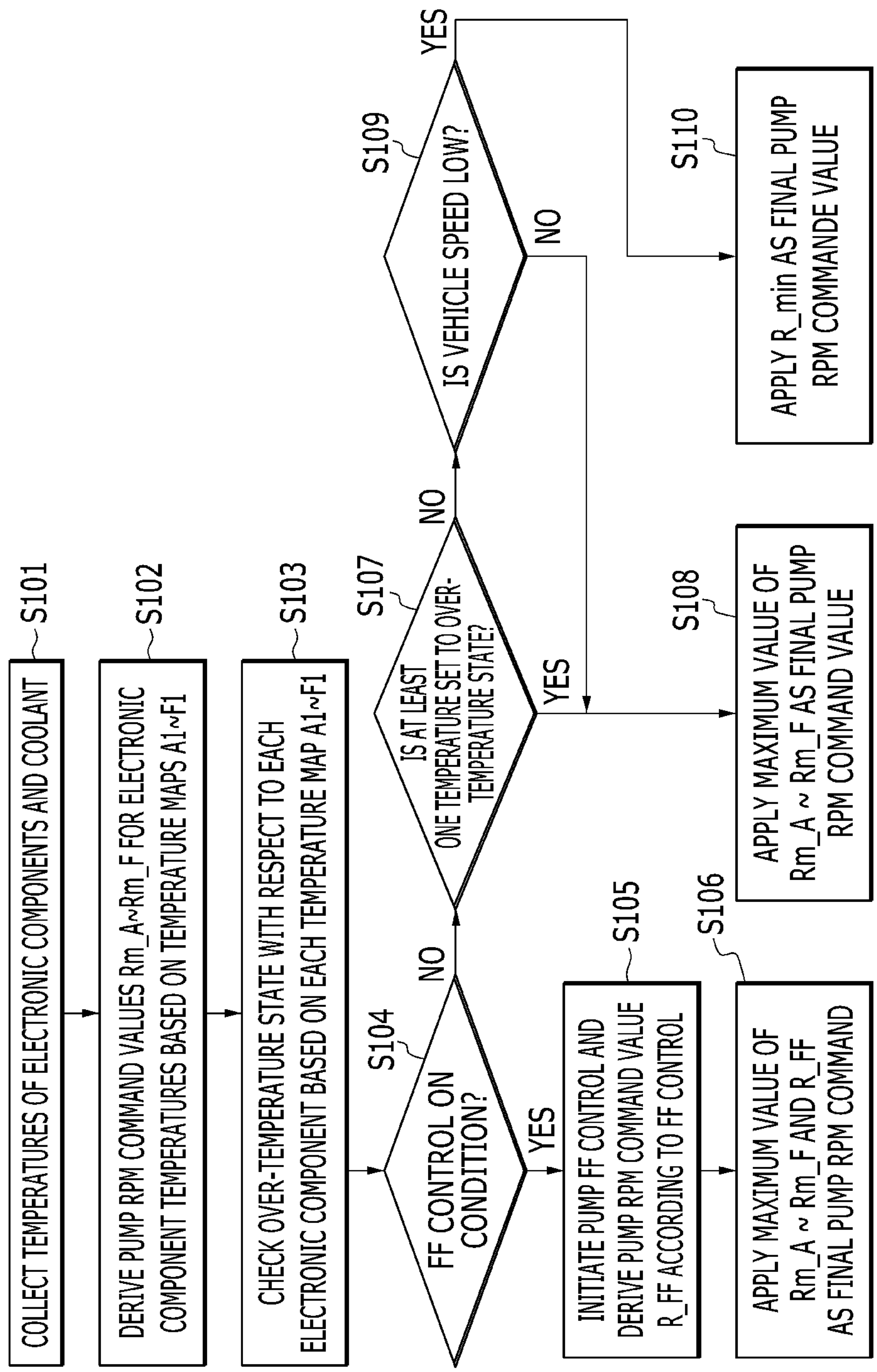
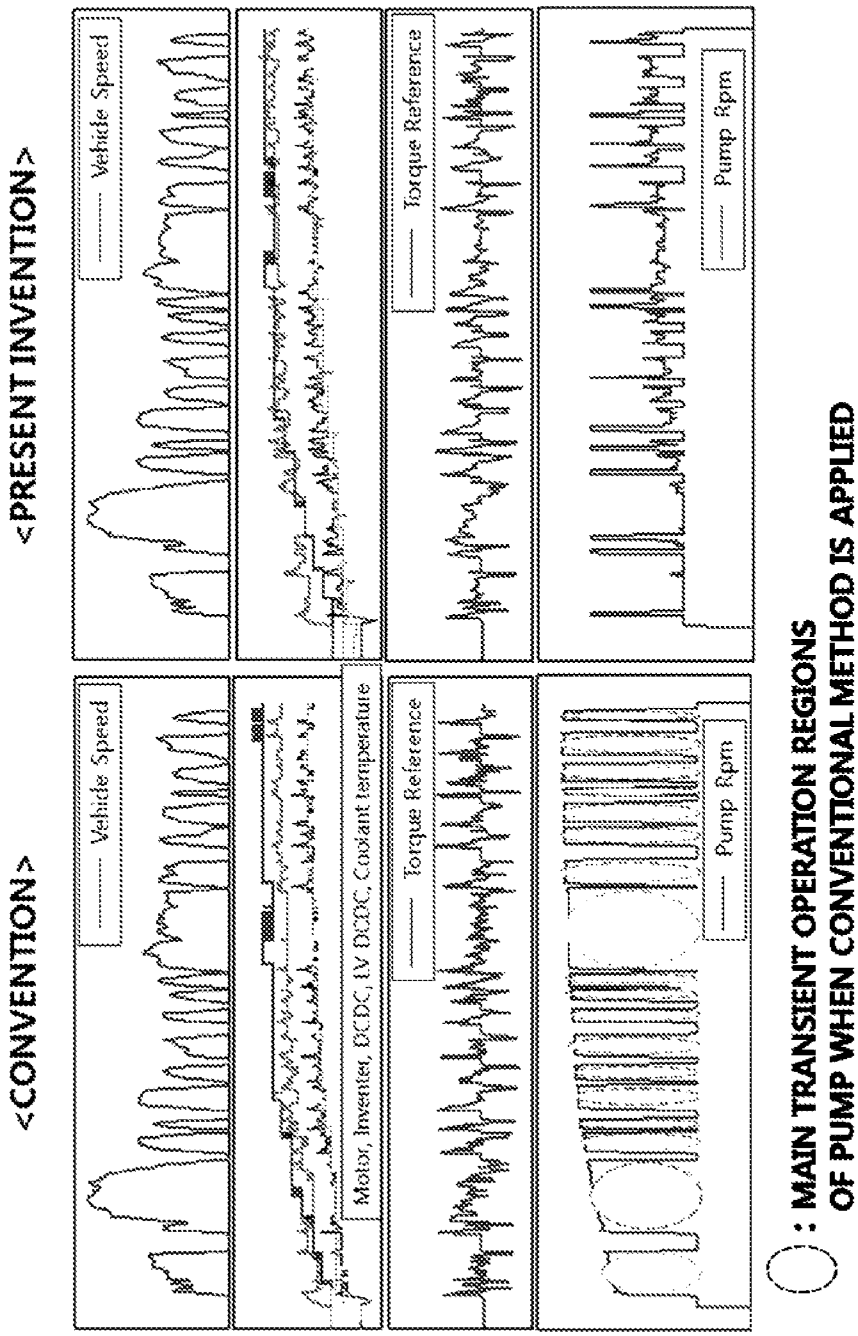

S101
COLLECT TEMPERATURES OF ELECTRONIC COMPONENTS AND COOLANT
S102
DERIVE PUMP RPM COMMAND VALUES Rm_A~Rm_F FOR ELECTRONIC COMPONENT TEMPERATURES BASED ON TEMPERATURE MAPS A1~F1
S103
CHECK OVER-TEMPERATURE STATE WITH RESPECT TO EACH ELECTRONIC COMPONENT BASED ON EACH TEMPERATURE MAP A1~F1
S104
FF CONTROL ON CONDITION?
YES
NO
S105
INITIATE PUMP FF CONTROL AND DERIVE PUMP RPM COMMAND VALUE R_FF ACCORDING TO FF CONTROL
S106
APPLY MAXIMUM VALUE OF Rm_A ~ Rm_F AND R_FF AS FINAL PUMP RPM COMMAND
S107
IS AT LEAST ONE TEMPERATURE SET TO OVER-TEMPERATURE STATE?
YES
NO
S108
APPLY MAXIMUM VALUE OF Rm_A ~ Rm_F AS FINAL PUMP RPM COMMAND VALUE
S109
IS VEHICLE SPEED LOW?
YES
NO
S110
APPLY R_min AS FINAL PUMP RPM COMMANDE VALUE

FIG. 5


<CONVENTION>
<PRESENT INVENTION>
Vehicle Speed
Motor, Inverter, DCDC, LV DCDC, Coolant temperature
Torque Reference
Pump Rpm
Vehicle Speed
Torque Reference
Pump Rpm
: MAIN TRANSIENT OPERATION REGIONS
OF PUMP WHEN CONVENTIONAL METHOD IS APPLIED

APPARATUS AND METHOD FOR CONTROLLING COOLING OF ELECTRONIC COMPONENTS OF FUEL CELL VEHICLE

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to and the benefit of Korean Patent Application No. 10-2013-0063706 filed in the Korean Intellectual Property Office on Jun. 3, 2013, the entire contents of which are incorporated herein by reference.

BACKGROUND

1. Technical Field

The present disclosure relates to an apparatus and method for controlling cooling of electronic components of a fuel cell vehicle.

2. Background

In general, a fuel cell is composed of an electrode producing an electrochemical reaction, an electrolyte membrane for transferring hydrogen ions generated by the electrochemical reaction and a bipolar plate for supporting the electrode and the electrolyte membrane.

Electronic components included in a fuel cell vehicle are heated to 80° C. when the fuel cell is operated in a full power state, and thus the electronic components must be cooled using coolant.

FIG. **1** illustrates electronic components and a coolant loop of a conventional fuel cell vehicle.

Referring to FIG. **1**, the fuel cell vehicle includes a motor **10**, an inverter **20** for the motor, a high voltage DC-DC converter **30** (referred to as HV DC-DC hereinafter) and a low voltage DC-DC converter **40** (referred to as LV DC-DC hereinafter) as electronic components.

It is difficult to provide an individual coolant loop for each of the electronic components due to costs and packaging issues. Accordingly, the electronic components are connected in series and parallel with a coolant loop and cooled through a pump **50**. This requires efficient cooling control.

However, a conventional cooling control technique cannot efficiently control cooling of the inverter **20** performing Insulated Gate Bipolar mode Transistor (IGBT) switching, HV DC-DC converter **30** and LV DC-DC converter **40** since the pump **50** is driven based on a signal of a coolant temperature sensor (not shown) attached to the coolant loop. To solve this problem, the conventional cooling control technique excessively drives the pump **50** even when the coolant temperature sensor signal indicates a relatively low temperature. This reduces fuel efficiency and generates noise.

The above information disclosed in this background section is only for enhancement of understanding of the background of the disclosure.

SUMMARY

The present disclosure has been made in an effort to provide an apparatus and method for controlling cooling of electronic components of a fuel cell vehicle having advantages of efficiently controlling operating temperatures of a motor and electronic components performing IGBT switching, which are connected through a serial and parallel coolant loop, to be maintained in an allowable range.

Another object of the present disclosure is to provide an apparatus and method for controlling cooling of electronic components of a fuel cell vehicle, which reduce noise through minimum operation of a pump in a transient operation period and minimize operation of the pump in an operation region other than a high torque region, improving fuel efficiency.

An exemplary embodiment of the present disclosure provides an apparatus for controlling cooling of electronic components connected in series and parallel with a coolant loop in a fuel cell vehicle using a pump, including: a monitor configured to collect measured temperature of the electronic components and a measured temperature of a coolant through a plurality of temperature sensors; and a controller configured to control the RPM of the pump based on the measured temperatures and at least one of electronic component temperature maps, a coolant temperature map and a temperature difference map representing temperature differences between the electronic components and coolant, the controller controlling the RPM of the pump using over-temperature set information and over-temperature reset information of each temperature map.

Another embodiment of the present disclosure provides an apparatus for controlling cooling of electronic components connected in series and parallel with a coolant loop in a fuel cell vehicle using a pump, including: a monitor configured to collect measured temperature of the electronic components and a measured temperature of coolant through a plurality of temperature sensors; and a controller configured to control the RPM of the pump based on the measured temperatures and at least one of electronic component temperature maps, a coolant temperature map and a map representing temperature differences between the electronic components and coolant, the controller performing feed-forward (FF) control for increasing the RPM of the pump preemptively upon detection of continuation of high torque and high temperature state for a predetermined time based on a motor torque reference value and an inverter temperature.

The electronic components may include at least one of a motor, an inverter, a high voltage DC-DC converter and a low voltage DC-DC converter, and the temperature maps may include pump RPM command value information for cooling control according to the measured temperature.

The controller may derive pump RPM command values for the measured temperatures of the electronic components and coolant, collected by the monitor, based on the electronic temperature maps, coolant temperature map and temperature difference map. When at least one of a motor temperature, an inverter temperature, an HV DC-DC converter temperature, an LV DC-DC converter temperature, and temperature differences between the electronic components and coolant exceeds a predetermined over-temperature reference value, the controller may determine that an electronic component corresponding to the temperature is in an over-temperature set state and apply a maximum value of pump RPM command values derived through the temperature maps as a final pump RPM command value.

When all the measured temperatures are lower than the over-temperature reference value and a vehicle speed is not low, the controller may apply the maximum value of the pump RPM command values derived through the temperature maps as the final pump RPM command value.

The controller may initiate feed-forward control for setting the RPM of the pump to higher than a normal value when a state that the motor torque reference value is higher than a first reference value for judgment of a high torque and the inverter temperature is higher than a second reference value for judgment of a high temperature is maintained for a time corresponding to a predetermined third reference value.

The controller may cancel the feed-forward control and return the pump RPM to the normal value when a state that the motor torque reference value is lower than a fourth reference value corresponding to a high torque state and the inverter temperature is lower than a fifth reference value corresponding to a high temperature state is maintained for a time corresponding to a predetermined sixth reference value.

The controller may detect a transient operation period in which the vehicle is in idling and creeping speed regions and apply a predetermined low RPM as a final pump RPM command value.

Yet another embodiment of the present disclosure provides a method for controlling cooling of electronic components connected in series and parallel with a coolant loop in a fuel cell vehicle using a pump, including: collecting measured temperature of the electronic components and a measured temperature of coolant through a monitor; deriving pump RPM command values corresponding to the measured temperatures based on at least one of electronic component temperature maps, a coolant temperature map and a temperature difference map representing temperature differences between the electronic components and coolant; checking an over-temperature state with respect to each measured temperature based on each temperature map and setting an over-temperature set state and an over-temperature reset state of each measured temperature; performing feed-forward control for increasing the RPM of the pump when a high torque and high temperature state is maintained for a predetermined time based on a motor torque reference value and an inverter temperature; and applying a maximum value of the pump RPM command values derived through the temperature maps as a final pump RPM command value when the feed-forward control condition is not satisfied and at least one of the measured temperatures corresponds to the over-temperature set state (OT_Set).

The deriving of the pump RPM command values may include deriving a pump RPM command value for at least one of a motor temperature, an inverter temperature, a high voltage DC-DC converter temperature, a low voltage DC-DC converter temperature, and temperature differences between the electronic components and coolant.

The setting of the over-temperature set state and over-temperature reset state may include checking whether at least one of a motor temperature, an inverter temperature, a high voltage DC-DC converter temperature, a low voltage DC-DC converter temperature, and temperature differences between the electronic components and coolant corresponds to an over-temperature state.

The performing of feed-forward control may include deriving a feed-forward pump RPM command value as a value greater than a predetermined percent of a maximum pump RPM upon initiation of feed-forward control; and applying a maximum value from among the pump RPM command values for the measured temperatures and the feed-forward pump RPM command value as a final pump RPM command value.

The method may further include controlling the final pump RPM command value to be a value lower than a predetermined percent of the maximum pump RPM when the feed-forward control condition is not satisfied, each measured temperature corresponds to the over-temperature reset state and the vehicle is in a parking state, neutral state or low-speed state corresponding to a speed lower than a predetermined speed.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates electronic components and a coolant loop of a conventional fuel cell vehicle.

FIG. **2** is a block diagram of an apparatus for controlling cooling of electronic components of a fuel cell vehicle according to an exemplary embodiment of the present disclosure.

FIG. **3** shows temperature maps used for cooling control according to an exemplary embodiment of the present disclosure.

FIG. **4** is a flowchart illustrating a method for controlling cooling of electronic components of a vehicle according to an exemplary embodiment of the present disclosure.

FIG. **5** shows graphs comparing electronic component cooling control results of a conventional method with electronic component cooling control results of the method according to the exemplary embodiment of the present disclosure.

DETAILED DESCRIPTION

An apparatus and method for controlling cooling of electronic components of a fuel cell vehicle according to exemplary embodiments of the present disclosure will now be described in detail with reference to the attached drawings.

FIG. **2** is a block diagram of an apparatus for controlling cooling of electronic components of a fuel cell vehicle according to an exemplary embodiment of the present disclosure.

Referring to FIG. **2**, an apparatus **100** for controlling cooling of electronic components of a fuel cell vehicle includes a monitor **110** for collecting measured temperatures of electronic components of the fuel cell vehicle and a controller **120** for controlling the RPM of a pump based on the measured temperatures.

The electronic components may include a motor, an inverter, an HV DC-DC and an LV DC-DC. A coolant loop of the fuel cell vehicle is connected in series and parallel with the electronic components and the electronic components are cooled through a pump.

The monitor **110** collects measured temperatures of the electronic components and a measured temperature of a coolant through a motor temperature sensor **111**, an inverter temperature sensor **112**, an HV DC-DC temperature sensor **113**, an LV DC-DC temperature sensor **114** and a coolant temperature sensor **115** in real time.

In addition, the monitor **110** can monitor the overall operating state of the vehicle, such as a shift-speed, vehicle speed, etc., in connection with controllers (not shown) in the vehicle.

The controller **120** controls the RPM of the pump based on at least one of electronic component temperature maps, a coolant temperature map and a temperature difference map representing temperature differences between the electronic components and coolant. Here, the controller **120** efficiently controls the RPM of the pump using over-temperature set (OT_Set) information and over-temperature reset (OT_Reset) information of the temperature maps.

FIG. **3** illustrates temperature maps used for cooling control according to an exemplary embodiment of the present disclosure.

Referring to FIG. **3**, the controller **120** stores a motor temperature map A1, an inverter temperature map B1, an HV DC-DC temperature map C1, an LV DC-DC temperature map D1, a coolant temperature map E1 and a temperature difference map F1 representing temperature differences between the electronic components and coolant.

In FIG. **3**, temperatures are denoted by Tn_A, Tn_B, Tn_C, Tn_D, Tn_E and Tn_F and pump RPM command values corresponding to the temperatures are denoted by Rm_A, Rm_B, Rm_C, Rm_D, Rm_E and Rm_F.

The controller **120** derives pump RPM command values for temperatures of the electronic components and coolant, collected by the monitor **110**, based on the electronic component temperature maps A1, B1, C1 and D1, the coolant temperature map E1 and the temperature difference map F1.

For example, in the case of temperatures T2_A, T2_B, T2_C, T2_D, T2_E and T2_F, pump RPM command values R2_A, R2_B, R2_C, R2_D, R2_E and R2_F corresponding to the temperatures can be derived.

The controller **120** controls the RPM of the pump based on the measured temperatures collected by the monitor **110** and at least one of the electronic component temperature maps A1, B1, C1 and D1, coolant temperature map E1 and temperature difference map F1. A detailed control method is described through the following embodiments.

Exemplary Embodiment 1

The controller **120** controls the RPM of the pump using over-temperature set (OT_Set) information and over-temperature reset (OT_Reset) information of each map.

The controller **120** previously sets an over-temperature reference value for checking over-temperature state to each temperature map. When the motor temperature, inverter temperature, HV DC-DC temperature, LV DC-DC temperature, coolant representative temperature and a temperature difference between an electronic component and the coolant are higher than the over-temperature reference value, the controller **120** determines that the temperatures correspond to an over-temperature state (OT_Set). When the temperatures are lower than the over-temperature reference value, the controller **120** determines that the temperatures correspond to an over-temperature reset state (OT_Reset).

When the controller **120** confirms that at least one of the motor temperature, inverter temperature, HV DC-DC temperature, LV DC-DC temperature, coolant representative temperature and temperature difference corresponds to the over-temperature state (OT_Set), the controller **120** can apply a maximum value of pump RPM command values Rm_A to Rm_F for the measured temperatures as a final pump RPM command value.

Furthermore, when the controller **120** determines that the measured temperatures are lower than the over-temperature reference value, the controller **120** can apply the final pump RPM command value as a normal value. Here, the normal value may be one of pump RPM command values derived based on the temperature maps, which will be described hereinafter, or the average of the pump RPM command values.

Exemplary Embodiment 2

The controller **120** can detect continuation of a high-torque and high-temperature state for a predetermined time based on a motor torque reference and the inverter temperature to perform feed-forward (FF) control for increasing the RPM of the pump preemptively.

An FF control condition is described in detail through the following embodiment and reference values for the control condition can be set as follows.

TH1 and TH4 refer to reference values with respect to the motor high torque state and can be set to values in the range of 20 to 100% when a maximum value of a motor torque reference is 100%.

TH2 and TH5 refer to reference values with respect to inverter high temperature state and can be set to values in the range of 20° C. to 70° C.

TH3 and TH6 refer to reference durations for which the motor high torque state and inverter high temperature state are maintained and can be set to values in the range of 0.5 to 10 seconds.

The reference values are not limited to the above-described values and best values derived through various experiments can be applied as the reference values.

(1) FF Control on Condition: (Motor Torque Reference Value≥TH1) and (Inverter Temperature≥TH2) and (Duration≥TH3):

The controller **120** may initiate FF control when, in a state that a motor torque reference value is higher than the first reference value TH1, the inverter temperature is higher than the second reference value TH2 is maintained for a time corresponding to the third reference value TH3. Here, the RPM of the pump can be set higher than a normal value through FF control.

Although the motor torque reference value may be used to check whether the vehicle speed is high or low under the control condition, the motor torque reference value needs to be discriminated from the vehicle speed since the motor torque reference value may become different from the actual vehicle speed according to a gradient of a road.

That is, when the vehicle speed is applied, the actual vehicle speed decreases when the vehicle runs on a steep uphill road due to load of the road even if the motor torque reference value is higher than the first reference value TH1 corresponding to high speed control, and thus cooling performance is deteriorated in spite of high temperature.

On the contrary, when the vehicle runs on a steep downhill, the actual vehicle speed may increase due to downhill acceleration even if the motor torque reference value is lower than the first reference value TH1 corresponding to low speed control, and thus excessive cooling control is unnecessarily performed.

(2) FF Control Off Condition: (Motor Torque Reference Value<TH4) and (Inverter Temperature<TH5) and (Duration≥TH6):

When the motor torque reference value is lower than the fourth reference value TH4, the inverter temperature is lower than the fifth reference value TH5 and this state is maintained for a time corresponding to the sixth reference value TH6, the controller **120** may cancel FF control and return the RPM of the pump to the normal value.

(3) RPM Command Value when FF Control on: R_FF:

Upon initiation of FF control, the controller **120** may derive an FF pump RPM command value R_FF. Here, R_FF may be a value representing a high RPM greater than or equal to a predetermined percent (e.g. 40%) of the maximum pump RPM.

The controller **120** may detect a transient driving period in which the vehicle is in idling and creeping speed regions and minimizes operation of the pump as long as cooling of the electronic components is not generated, thereby reducing noise.

For example, the controller **120** may apply a low RPM R_min as a final pump RPM command value when the shift range is in parking P range or neutral N range or the vehicle speed is low, the temperatures of all electronic components correspond to low-temperature state OT_Reset based on the temperature maps and FF control is off. Here, R_min may be a value representing a low RPM less than a predetermined percent (e.g. 40%) of the maximum pump RPM.

Exemplary Embodiment 3

A description will be given of a method for controlling cooling of electronic components of a fuel cell vehicle according to an exemplary embodiment of the present disclosure based on the configuration of the above-described cooling control apparatus **100** including the first and second embodiments.

FIG. **4** is a flowchart illustrating a method for controlling cooling of electronic components of a fuel cell vehicle according to an exemplary embodiment of the present disclosure.

Referring to FIG. **4**, the cooling control apparatus **100** may collect electronic component temperatures and coolant temperature through the monitor **110** (S**101**).

The cooling control apparatus **100** may derive pump RPM command values Rm_A to Rm_F for the electronic component temperatures based on the temperature maps A1 to F1 (S**102**).

Step S**102** is described in detail.

The cooling control apparatus **100** may derive a pump RPM command value Rm_A for the motor temperature based on the motor temperature map A1.

The cooling control apparatus **100** may derive a pump RPM command value Rm_B for the inverter temperature based on the inverter temperature map B1.

The cooling control apparatus **100** may derive a pump RPM command value Rm_C for the HV DC-DC temperature based on the HV DC-DC temperature map C1.

The cooling control apparatus **100** may derive a pump RPM command value Rm_D for the LV DC-DC temperature based on the LV DC-DC temperature map D1.

The cooling control apparatus **100** may derive a pump RPM command value Rm_E for the current coolant representative temperature based on the coolant temperature map E1.

The cooling control apparatus **100** may derive a pump RPM command value Rm_F for the current temperature difference, which is a temperature difference between an electronic component and the coolant representative temperature, based on the temperature difference map F1.

The cooling control apparatus **100** may check an over-temperature state of each electronic component based on the corresponding temperature map A1 to F1 and set the over-temperature reference value when the temperature of the corresponding electronic component exceeds the over-temperature reference value (S**103**).

Step S**103** is further described below.

The cooling control apparatus **100** may check whether the current motor temperature corresponds to over-temperature state based on the motor temperature map A1 and set OT_A when the current motor temperature corresponds to over-temperature state.

The cooling control apparatus **100** may check whether the current inverter temperature corresponds to the over-temperature state based on the inverter temperature map B1 and set OT_B when the current inverter temperature corresponds to the over-temperature state.

The cooling control apparatus **100** may check whether the current HV DC-DC temperature corresponds to the over-temperature state based on the HV DC-DC temperature map C1 and set OT_C when the current HV DC-DC temperature corresponds to the over-temperature state.

The cooling control apparatus **100** may check whether the current LV DC-DC temperature corresponds to the over-temperature state based on the LV DC-DC temperature map D1 and set OT_D when the current LV DC-DC temperature corresponds to the over-temperature state.

The cooling control apparatus **100** may check whether the current coolant representative temperature corresponds to the over-temperature state based on the coolant temperature map E1 and set OT_E when the current coolant representative temperature corresponds to the over-temperature state.

The cooling control apparatus **100** may check whether the current temperature difference corresponds to the over-temperature state based on the temperature difference map F1 and set OT_F when the current temperature difference corresponds to the over-temperature state.

The cooling control apparatus **100** may check whether the FF control ON condition that a duration during which the motor torque reference value is higher than the first reference value TH1 and the inverter temperature is higher than the second reference value TH2 is longer than the time corresponding to the third reference value TH3 is satisfied (S**104**).

When the FF control ON condition is satisfied in step S**104**, the cooling control apparatus **100** may initiate pump FF control and derive a pump RPM command value R_FF according to FF control (S**105**).

The cooling control apparatus **100** may apply a maximum value of Rm_A to Rm_F and R_FF as a final pump RPM command value (S**106**).

When the FF control ON condition is not satisfied in step S**104**, the cooling control apparatus **100** may check whether at least one of the temperatures of the electronic components corresponds to the over-temperature state (S**107**).

When the cooling control apparatus **100** confirms that at least one of the temperatures of the electronic components corresponds to the over-temperature state, the cooling control apparatus may apply a maximum value of pump RPM command values Rm_A to Rm_F as a final pump RPM command value (S**108**).

When the cooling control apparatus **100** determines that the temperatures of the electronic components do not correspond to the over-temperature state in step S**107**, the cooling control apparatus **100** may check whether the vehicle speed is low (S**109**).

For example, the cooling control apparatus **100** applies R_min as the final pump RPM command value when the shift range corresponds to parking P range or neutral N range or the vehicle speed is lower than 20 kph (S**110**).

The cooling control apparatus **100** may perform step S**108** when the vehicle is not in a low-speed state under the above-described condition.

After step S**106**, pump FF state can be off if a state that the motor torque reference value is lower than the fourth reference value TH4 and the inverter temperature is lower than the fifth reference value TH5 is maintained for a time corresponding to the sixth reference value TH6.

The over-temperature state with respect to the electronic component temperature maps A1, B1, C1 and D1, coolant temperature map E1 and temperature difference map F1 may be cancelled when the temperatures of the electronic components and coolant are lower than the over-temperature reference value. When the over-temperature state is cancelled, over-temperature set may be reset (OT_A Reset to OT_F Reset).

FIG. **5** shows graphs comparing electronic component cooling control results of a conventional method with an electronic component cooling control results of the control method according to the exemplary embodiments of the present disclosure.

Referring to FIG. **5**, under the same vehicle and operation conditions, the conventional electronic component cooling control method indicates main transient operation regions of the pump and thus the pump is excessively driven in a transient operation period, reducing fuel efficiency and generating excessive noise.

On the other hand, the electronic component cooling control method according to the exemplary embodiments of the present disclosure can solve a noise problem caused by the pump during vehicle creep operation or idling after high power operation of the vehicle by reducing noise through minimum operation of the pump in the transient operation period.

It can be confirmed from a test result of an urban dynamometer driving schedule (UDDS) mode exclusive of the high torque region of the motor that fuel efficiency is improved by 1% or more compared to the conventional method.

Furthermore, pump RPM control using operating temperatures of electronic components such as a motor, inverter, HV DC-DC, LV DC-DC, etc. and over-temperature set and reset information can be performed to maintain the operating temperatures of the electronic components connected in series and parallel with a coolant loop in an allowable range.

Exemplary embodiments of the present disclosure may be implemented through programs for executing functions corresponding to configurations of the embodiments and recording media storing the programs as well as the above-described apparatus and/or method, and this implementation can be achieved by those skilled in the art according to the above-described embodiments.

While this disclosure has been described in connection with what is presently considered to be practical exemplary embodiments, it is to be understood that the disclosure is not limited to the disclosed embodiments, but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

What is claimed is:

1. An apparatus for controlling cooling of electronic components connected in series and parallel with a coolant loop in a fuel cell vehicle using a pump, comprising:

a monitor configured to collect a measured temperature of the electronic components and a measured temperature of a coolant through a plurality of temperature sensors; and

a controller configured to control a revolutions per minute (RPM) of the pump based on the measured temperatures and at least one of electronic component temperature maps, a coolant temperature map, and a temperature difference map representing temperature differences between the electronic components and the coolant, the controller controlling the RPM of the pump using over-temperature set information and over-temperature reset information of each temperature map,

wherein, when at least one of a motor temperature, an inverter temperature, a high voltage (HV) DC-DC converter temperature, a low voltage (LV) DC-DC converter temperature, and the temperature differences between the electronic components and the coolant exceeds an over-temperature reference value, the controller determines that an electronic component corresponding to the temperature is in an over-temperature set state and applies a maximum value of pump RPM command values derived through the temperature maps as a final pump RPM command value.

2. An apparatus for controlling cooling of electronic components connected in series and parallel with a coolant loop in a fuel cell vehicle using a pump, comprising:

a monitor configured to collect a measured temperature of the electronic components and a measured temperature of a coolant through a plurality of temperature sensors; and

a controller configured to control an RPM of the pump based on the measured temperatures and at least one of electronic component temperature maps, a coolant temperature map and a temperature difference map representing temperature differences between the electronic components and the coolant, the controller performing feed-forward (FF) control for increasing the RPM of the pump preemptively upon detection of continuation of a high torque and high temperature state for a predetermined period of time based on a motor torque reference value and an inverter temperature.

3. The apparatus of claim **1**, wherein the electronic components include at least one of a motor, an inverter, an HV DC-DC converter, and an LV DC-DC converter, and the temperature maps include pump RPM command value information for the cooling control according to the measured temperatures.

4. The apparatus of claim **1**, wherein the controller is further configured to derive the pump RPM command values for the measured temperatures of the electronic components and the coolant, collected by the monitor, based on the electronic temperature maps, the coolant temperature map, and the temperature difference map.

5. The apparatus of claim **1**, wherein, when all the measured temperatures are lower than the over-temperature reference value and a vehicle speed is not low, the controller applies the maximum value of the pump RPM command values derived through the temperature maps as the final pump RPM command value.

6. The apparatus of claim **2**, wherein the electronic components include at least one of a motor, an inverter, an HV DC-DC converter, and an LV DC-DC converter, and the temperature maps include pump RPM command value information for the cooling control according to the measured temperatures.

7. The apparatus of claim **2**, wherein the controller derives pump RPM command values for the measured temperatures of the electronic components and the coolant, collected by the monitor, based on the electronic temperature maps, the coolant temperature map, and the temperature difference map.

8. The apparatus of claim **2**, wherein the controller is configured to initiate the FF control for setting the RPM of the pump to higher than a normal value when the motor torque reference value is higher than a first reference value for judgment of a high torque and the inverter temperature is higher than a second reference value for judgment of a high temperature is maintained for a time corresponding to a third reference value.

9. The apparatus of claim **8**, wherein the controller is configured to cancel the FF control and returns the pump RPM to the normal value when a state that the motor torque reference value is lower than a fourth reference value corresponding to a high torque state and the inverter temperature is lower than a fifth reference value corresponding to a high temperature state is maintained for a time corresponding to a sixth reference value.

10. The apparatus of claim **1**, wherein the controller is configured to detect a transient operation period in which the vehicle is in idling and creeping speed regions and applies a predetermined low RPM as a final pump RPM command value.

11. The apparatus of claim **2**, wherein the controller is configured to detect a transient operation period in which the vehicle is in idling and creeping speed regions and applies a predetermined low RPM as a final pump RPM command value.

12. A method for controlling cooling of electronic components connected in series and parallel with a coolant loop in a fuel cell vehicle using a pump, comprising:

collecting a measured temperature of the electronic components and a measured temperature of a coolant through a monitor;

deriving pump RPM command values corresponding to the measured temperatures based on at least one of electronic component temperature maps, a coolant temperature map, and a temperature difference map representing temperature differences between the electronic components and the coolant;

checking an over-temperature state with respect to each measured temperature based on each temperature map and setting an over-temperature set state and an over-temperature reset state of each measured temperature;

performing FF control for increasing an RPM of the pump when a high torque and high temperature state is maintained for a predetermined period of time based on a motor torque reference value and an inverter temperature; and

applying a maximum value of the pump RPM command values derived through the temperature maps as a final pump RPM command value when an FF control condition is not satisfied and at least one of the measured temperatures corresponds to the over-temperature set state.

13. The method of claim 12, wherein the deriving of the pump RPM command values comprises deriving a pump RPM command value for at least one of a motor temperature, an inverter temperature, an HV DC-DC converter temperature, an LV DC-DC converter temperature, and the temperature differences between the electronic components and the coolant.

14. The method of claim 12, wherein the setting of the over-temperature set state and the over-temperature reset state comprises checking whether at least one of a motor temperature, an inverter temperature, an HV DC-DC converter temperature, an LV DC-DC converter temperature, and the temperature differences between the electronic components and the coolant corresponds to the over-temperature state.

15. The method of claim 12, wherein the performing of feed forward the FF control comprises:

deriving a FF pump RPM command value as a value greater than a predetermined percent of a maximum pump RPM upon initiation of the FF control; and

applying a maximum value from among the pump RPM command values for the measured temperatures and the FF pump RPM command value as a final pump RPM command value.

16. The method of claim 12, further comprising controlling the final pump RPM command value to be a value lower than a predetermined percent of the maximum pump RPM when the FF control condition is not satisfied, each measured temperature corresponds to the over-temperature reset state and the vehicle is in a parking state, neutral state or low-speed state corresponding to a speed lower than a predetermined speed.

* * * * *